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FINAL REPORT

NASA Grant NAGW-3044

Observations of Spacecraft Targets, Unusual Asteroids,
and Targets of Opportunity

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Dates

1992 April 1 to 1998 March 31

Location

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Goals

Obtain physical and astrometric observations of (a) spacecraft targets to support mission operations, (b) known asteroids with unusual orbits to help determine their origin, and (c) newly discovered minor planets (including both asteroids and comets) that represent a particular opportunity to add significant new knowledge of the Solar System.

Observations and Data Analysis

Priority was given to the acquisition and analysis of observations of spacecraft targets, including (951) Gaspra and (243) Ida, both flyby targets of the *Galileo* spacecraft, (1620) Geographos, a flyby target for the *Clementine* spacecraft, (253) Mathilde and (433) Eros, both targets of the *NEAR* spacecraft, (4660) Nereus, a target for both the *MUSES-C* and *NEAP* missions, P/Wild 2, a target for the *Stardust* mission, and P/Wirtanen, a target for the *Rosetta* mission. Although the observations of Gaspra were obtained under an earlier grant, the analysis and publication of those data continued under this grant. Observations of Ida included both lightcurve data that were combined with similar data obtained by others to develop a pre-encounter shape and spin axis orientation model, thermal infrared data to determine a radiometric size and geometric albedo for the asteroid, and astrometry to assist with the spacecraft navigation effort, which had been compromised by the high-gain antenna problem. Although *Clementine* did not succeed in getting to Geographos, a wealth of new ground-based lightcurve observations, including some obtained with support from this grant, were used to develop a shape and spin model for the asteroid, comparable to the one done for Ida. One set of colors were obtained for Mathilde, and some critical astrometry was acquired shortly after solar conjunction, just before the encounter. No new colorimetric data were obtained for Eros, though lightcurve data were extracted from the Eight Color Asteroid Survey archive and provided to A. W. Harris (JPL) for inclusion in a paper presenting his own observations of Eros; some new astrometric observations of Eros were acquired. Considerable effort was expended to observe Nereus, for which no previous physical observations existed. The 1992-1993 apparition was the most favorable for the remainder of the decade, and the colors obtained at that time favored the X spectral classification (the E, M, and P

classes are spectrally degenerate and separate on the basis of geometric albedo, which remains unknown for Nereus), raising the possibility that Nereus is a nickel-iron object. During the less favorable 1997 apparition, observations of the rotational lightcurve were acquired. The large brightness variation (in excess of 1 magnitude) showed Nereus to be an elongated object, rotating rather slowly (period of about 15 hours). If the object has a high albedo, and therefore a smaller size than currently estimated, its time scale for damping to a state of principal axis rotation could be comparable to its lifetime, so these observations have raised the possibility that Nereus is tumbling. Observations of P/Wild 2 consisted of a few images to monitor activity, while the only observations of P/Wirtanen were to attempt recovery.

The two most exciting objects that fell into the target of opportunity category were (5145) Pholus (designated as 1992 AD at the time of discovery) and comet P/Shoemaker-Levy 9. Colorimetric observations of Pholus with the IRTF led to the discovery that Pholus is the reddest asteroid in the Solar System over the visible to near-infrared portions of the spectrum, and also led to the creation of a new Z taxonomic class. Higher resolution spectral observations obtained with the UKIRT identified some absorption features in the near-infrared that colleagues have been modeling for some time. Observations of P/Shoemaker-Levy 9 fell into two categories. First were the astrometric observations, used to help refine the times of impact. In fact, we were able to provide the very last set of astrometric positions for some of the fragments, quite close to Jupiter, thanks to the excellent conditions at Mauna Kea Observatory. Second was some high-speed photometry intended to observe reflections of the flash events off a suitably placed Galilean satellite. Four of the impact events occurred within the observation window for Mauna Kea. Poor weather (including a hurricane for one of them) precluded observations of two of the events. A third was observed in very strong twilight, while excellent data were obtained for the fourth, though in no case was a detectable flash signal obvious in the data.

In the unusual asteroid category are primarily the Earth approaching and trans-Neptunian populations. Colorimetry of numerous near-Earth asteroids was obtained; most of these data are being incorporated into doctoral candidate Robert Whiteley's thesis, which is currently slated for completion in the summer of 1999. Selected observations have already been published, such as for 1996 JA1 and Geographos, when there was an opportunity to combine results with those obtained by others. Astrometric observations of the newly discovered and unnumbered near-Earth asteroids have routinely been reported to the Minor Planet Center. Objects for which observations have been secured include:

(1036) Ganymed	(3671) Dionysus	(4954) Eric
(1620) Geographos	(3752) Camillo	(5143) Heracles
(1864) Daedalus	(3753) Cruithne	(5189) 1990 UQ
(1980) Tezcatlipoca	(4015) Wilson-Harrington	(5332) 1990 DA
(2059) Baboquivari	(4179) Toutatis	(5604) 1992 FE
(2062) Aten	(4183) Cuno	(5626) 1991 FE
(2102) Tantalus	(4197) 1982 TA	(5646) 1990 TR
(2201) Oljato	(4341) Poseidon	(5653) 1992 WD5
(3102) Krok	(4660) Nereus	(5693) 1993 EA
(3200) Phaethon	(4953) 1990 MU	(5751) Zao

(5786) Talos	(8176) 1991 WA	1993 VC
(5836) 1993 MF	(8201) 1994 AH2	1993 WD
(5863) Tara	(9058) 1992 JB	1994 AW1
(5879) 1992 CH1	1990 BA	1994 GY
(6053) 1993 BW3	1990 SB	1994 LW
(6063) Jason	1991 BB	1994 NE
(6455) 1992 HE	1991 VH	1994 QC
(6489) Golevka	1992 BF	1994 TF2
(6569) 1993 MO	1992 BL2	1996 FG3
(6611) 1993 VW	1992 CC1	1996 XW1
(7025) 1993 QA	1992 JE	1997 BQ
(7350) 1993 VA	1992 SL	1997 BR
(7480) Norwan	1992 WR4	1997 MW1
(7482) 1994 PC1	1993 BX3	1997 NC1
(7753) 1988 XB	1993 DA	1997 QK1
(7822) 1991 CS	1993 DC	1997 RT
(7839) 1994 ND	1993 KA	1997 US9
(7888) 1993 UC	1993 KH	1997 VM4
(7889) 1994 LX	1993 QP	1998 BY7
(7977) 1977 QQ5	1993 TQ2	1998 BZ7
(8034) 1992 LR	1993 UB	1998 BB10

(4179) Toutatis was a particularly interesting target. The combination of Ostro's radar images and the ground-based photometry conclusively show this object to be tumbling.

Colorimetric observations of Centaurs and trans-Neptunian objects have proven to be the most snake-bit of the projects covered by this grant, in terms of not getting photometric weather. Fortunately, it's been possible to extract astrometry on some of the non-photometric nights, so the work hasn't been a total loss. A run on the ESO NTT (in collaboration with M. A. Barucci) may have been the most successful of the attempts so far, and those data have recently been submitted for publication. Objects for which some data have been acquired include:

(2060) Chiron	1994 GV9	1996 TO66
(5145) Pholus	1994 JR1	1996 TP66
(7066) Nessus	1994 TB	1997 CQ29
(8405) 1995 GO	1994 VK8	1997 CR29
1992 QB1	1995 DA2	1997 CT29
1993 FW	1995 DW2	1997 CU29
1993 RO	1995 QY9	1997 CV29
1993 RP	1995 YY3	1997 CW29
1993 SB	1996 RQ20	1997 QH4
1993 SC	1996 TL66	1997 RY6

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Astrometry and/or orbit computations for minor planets and/or comets have been published in the following *Minor Planet Circulars* (note that in late 1997, astrometry of asteroids was moved to a *Supplement*):

MPC 31340 (1998)	MPC 28177 (1996)	MPC 23720 (1994)
MPC 31339 (1998)	MPC 26840 (1996)	MPC 23719 (1994)
MPS 565 (1998)	MPC 26491 (1996)	MPC 23707 (1994)
MPC 31196 (1998)	MPC 26263 (1996)	MPC 23706 (1994)
MPS 453 (1998)	MPC 25995 (1995)	MPC 23703 (1994)
MPS 464 (1998)	MPC 25994 (1995)	MPC 23701 (1994)
MPC 31061 (1998)	MPC 25792 (1995)	MPC 23700 (1994)
MPS 286 (1998)	MPC 25691 (1995)	MPC 23583 (1994)
MPS 287 (1998)	MPC 25677 (1995)	MPC 23582 (1994)
MPC 30838 (1997)	MPC 25482 (1995)	MPC 23022 (1994)
MPS 174 (1997)	MPC 25462 (1995)	MPC 22850 (1994)
MPC 30562 (1997)	MPC 25372 (1995)	MPC 22632 (1993)
MPC 30349 (1997)	MPC 25020 (1995)	MPC 22304 (1993)
MPC 30146 (1997)	MPC 25019 (1995)	MPC 22145 (1993)
MPC 30145 (1997)	MPC 24967 (1995)	MPC 22008 (1993)
MPC 29992 (1997)	MPC 24037 (1994)	MPC 21692 (1993)
MPC 29991 (1997)	MPC 23904 (1994)	MPC 19594 (1992)
MPC 29738 (1997)	MPC 23819 (1994)	
MPC 28979 (1997)	MPC 23818 (1994)	

Critical astrometric observations have been published on the following *Minor Planet Electronic Circulars*:

MPEC 1998-B31 (1998)	1998 BR26
MPEC 1997-R15 (1997)	1996 SZ4
MPEC 1997-R14 (1997)	1996 RQ20
MPEC 1997-R10 (1997)	1997 RT
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MPEC 1995-M06 (1995)	1995 LG
MPEC 1995-M05 (1995)	1995 LE
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MPEC 1994-D02 (1994)	Periodic Comet Shoemaker-Levy 9 (1993e)

Items of particular urgency have been published on the following *International Astronomical Union Circulars*:

IAUC 6764	1997 Oct 31	Satellites of Uranus
IAUC 6402	1996 May 18	1996 JA1
IAUC 6264	1995 Nov 18	Comet 45P/Honda-Mrkos-Pajdusakova
IAUC 6030	1994 Jul 20	Periodic Comet Shoemaker-Levy 9 (1993e)
IAUC 5983	1994 May 3	1993 SC
IAUC 5698	1993 Jan 27	(5145) Pholus
IAUC 5434	1992 Jan 23	1992 AD

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